Long-term Effects of Orthodontic Forces on the Morphology of the Rat-incisor Socket and its Location in the Mandible

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What is This?
The effect of orthodontic force application on the rat-incisor socket and mandible was studied using roentgenograms. A mean linguo-intrusive force of 19 ± 0.6 g was applied continuously to the shortened left lower incisor for a period of two (group A) and four weeks (group B). A third group of rats, subjected to shortening of the left mandibular incisor only, served as a hypofunctional control (group C). A fourth group of normal rats constituted the intact control (group D). After a recovery period of three months, the animals were killed, and standardized roentgenograms of the cleaned mandibles were taken. Socket and mandibular dimensions were measured on magnified tracings of the roentgenograms. Comparison of groups A and B with the control groups, on the one hand, and of group C with group D, on the other, facilitated isolation of the hypofunctional factor. In groups A and B, the orthodontic forces caused changes in the parameters affected (i.e., socket area, alveolar bone thickness, mandibular dimensions) and not affected by hypofunction (i.e., socket angulation and location, anterior-socket length). The former finding implies modification of the adaptive capability of dental structures to functional demands. It is concluded that mechanical loading of the incisor for two to four weeks causes long-lasting changes in the socket and its surrounding bone.


Introduction.

The effects of mechanical forces on dental and periodontal tissues remain a subject of interest. Animal studies have revealed retarded eruption (Steigman et al., 1983, 1988), as well as structural derangements of the rat incisor and its periodontal ligament (PDL) (Michaeli et al., 1985; Engström and Noren, 1986; Michaeli et al., 1987; Steigman et al., 1987), following force application to teeth. Reports also exist on the adjustment of the continuously erupting incisor, its socket, and mandible to retarded and accelerated eruption (Moxham and Berkovitz, 1981; Brin et al., 1989; Steigman et al., 1989), or to other functional demands (Beecher and Corruccini, 1981; Bondevik, 1984; Kiliaridis et al., 1985; McFadden et al., 1986; Kjellberg et al., 1987). Both elimination and increase of functional occlusal forces were found to induce changes in morphology, dimensions, and location of the socket (Brin et al., 1989). Little is known, however, about structural adjustment of the socket following orthodontic force application, particularly when coupled with changed functional demands. The present study was conducted on rats and was designed (1) to describe the long-term morphological effects of orthodontic force on the mandible and the incisor socket; (2) to assess the influence of mechanical loading on the capability of tissue to adjust to altered functional demands, and (3) to study the effect of orthodontic force duration on the morphology and location of the socket.

Materials and methods.

For this investigation, 51 female adult rats of the Sabra strain (mean weight, 215 ± 3 g) were used. The animals were housed in standard metal cages and fed a Purina chow pellet diet and water ad libitum. In 18 rats, a mean linguo-intrusive force of 19 ± 0.6 g was applied continuously to the shortened left incisor. In ten animals, the spring remained attached for two weeks (group A), and in eight rats, for a period of four weeks (group B). Loading was accomplished under chloral hydrate anesthesia by means of a 0.13 × 0.53 mm Elgiloys closed-coil spring (Rocky Mountain Orthodontics, Denver, CO) that was stretched between the left mandibular molar and the left incisor (Steigman et al., 1981). After removal of the loads, the left incisors were kept out of occlusion for an additional period of three months by being repeatedly shortened. In 12 other rats, not subjected to orthodontic forces, the lower-left incisor was also shortened repeatedly (every third day) for a period of three months, so that unimpeded eruption could be obtained (group C: hypofunctional control). A group of 15 animals served as control for all experimental sets (group D; intact control). The remaining six animals served for evaluation of the mode of tooth movement (group E). In this group, orthodontic force was applied for two weeks, after which they were killed with the springs still in situ.

The rate of eruption of the lower-left incisors of groups A, B, C, and D was measured every third day under ether anesthesia for a period of three months, as described elsewhere (Michaeli and Weinreb, 1968). The animals were killed by an overdose of ether. The mandibles were dissected, cleaned of soft tissue, and fixed in Bouin-Holland solution. Standardized non-distorted lateral radiographs were taken of the left mandibles. The radiographs were projected on a screen (magnification × 4.5), and the outlines of the mandibular bone and of the incisor socket were traced on acetate paper. The tracings were oriented on the mandibular plane (constructed so as to form a tangent to the lower border of the mandible) and measured directly. Area measurements were performed by means of a special computer program, after the tracings were digitized.

The following reference points were identified on the tracings (Fig. 1a, b): (1) the most anterior point on the lingual alveolar bone; (2) the deepest point on the lingual alveolar bone contour; (2') the intersection between the lingual outline of the socket and a perpendicular line (through point 2) to the mandibular plane; (3) the intersection between the mandibular alveolar bone and the mesial surface of the first molar; (4) the most anterior point on the curvature between the coronoid and the condylar processes; (5) the most posterior point on the condylar process; (6) the most anterior point on the mandibular ramus; (7) the most posterior point on the angular process; (8) the most inferior point on the angular process; (9) the deepest point on the antegonial notch; (10) the most inferior point on the

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the labial alveolar bone contour; (10') the intersection between the labial outline of the socket and a perpendicular line (through point 10) to the mandibular plane; (11) the most anterior point on the labial alveolar bone; (12) the most posterior/superior point of the socket; (12') the intersection between the coronoid process and a perpendicular line (through point 12) to the mandibular plane; (12'') the intersection between the inferior mandibular border and a perpendicular line (through point 12) to the mandibular plane; (13) the most inferior point on the labial contour of the socket.

These landmarks were used for delineation of morphological features and dimensions of the socket and mandible, as well as for determination of the location of the socket within the mandible, as follows:

I. Morphology of the mandible (Fig. 1a).—(1) anterior height (measured on the perpendicular line from point 2 to the mandibular plane); (2) posterior height (measured on the perpendicular from point 4 to the mandibular plane); (3) anterior length (1-3); (4) posterior length (3-5, 3-6, 3-7, 3-8, 3-9); (5) gonial angle (5-7/mandibular plane); and (6) net area (total mandibular area less socket area).

II. Morphology, dimensions, and location of the socket (Fig. 1b).—(1) angulation (11-12-13); (2) anterior length (11-13); (3) posterior length (13-12); (4) area; (5) anterior vertical location—(a) superior (2-2'), (b) inferior (10-10'); (6) posterior vertical location—(a) superior (12-12'), (b) inferior (12-12''); and (7) posterior horizontal location (5-12).

Group E was included in the study, for detection of the actual type of tooth movement elicited by the orthodontic force per se. To that end, the position of the socket in the anterior and posterior regions in this group was recorded and compared with the corresponding measurements of control group D. In addition, the tracings performed on group E were superimposed on those of group D. The occlusal plane served as the plane of superposition with registration on the last molar (Fig. 2a, b).

Statistical analysis.—The means (± standard error) of the measurements were calculated. ANOVA was applied for comparison between the means of the four groups. So that significant differences between groups could be detected, the Scheffé method for multiple comparisons was used, with a significance level of 5%.

Results.

The animals withstood the experimental procedures well and appeared to be normal and healthy throughout the investigation. Their mean weight was similar in all groups, reaching 245 ± 5 g at the end of the experimental period.

The mean daily eruption rate of the incisors in control group D was 443 ± 5 μm. The unimpeded eruption rate in group C was doubled, while in groups A and B, eruption was greatly impaired, the rates reaching 849 ± 30 μm, 577 ± 34 μm, and 208 ± 82 μm, respectively, at the end of the experiment.

The orthodontic forces brought about either rotation of the incisor around a fulcrum situated in the middle tooth third (Fig. 2a) or a tooth movement in which the fulcrum was located at the level of the alveolar crest (Fig. 2b). In the rats killed immediately after two weeks of force application (group E), the socket had attained a significantly more superior location anteriorly (p<0.01) and more inferior posteriorly (p<0.05), compared with group D. The mean 2-2' distance changed from 1.63 ± 0.05 mm to 1.18 ± 0.10 mm, and the mean 12-12'' distance decreased from 8.43 ± 0.37 mm to 7.07 ± 0.28 mm.

Mandible (Table 1, Fig. 1a).—The mandibular vertical dimension remained unaffected by unimpeded eruption per se.
TABLE 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior height (mm)</td>
<td>5.15 ± 0.17</td>
<td>5.67 ± 0.08</td>
<td>5.50 ± 0.11</td>
<td>5.40 ± 0.07</td>
</tr>
<tr>
<td>Posterior height (mm)</td>
<td>12.64 ± 0.19</td>
<td>12.68 ± 0.14</td>
<td>12.75 ± 0.20</td>
<td>12.30 ± 0.28</td>
</tr>
<tr>
<td>Anterior length (mm)</td>
<td>8.35 ± 0.18</td>
<td>7.65 ± 0.17**</td>
<td>8.56 ± 0.14</td>
<td>8.62 ± 0.14</td>
</tr>
<tr>
<td>Posterior length (mm):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 - 5</td>
<td>21.80 ± 0.19*</td>
<td>22.28 ± 0.10**</td>
<td>21.47 ± 0.16*</td>
<td>20.27 ± 0.28</td>
</tr>
<tr>
<td>3 - 6</td>
<td>18.46 ± 0.10*</td>
<td>18.57 ± 0.11**</td>
<td>17.81 ± 0.17</td>
<td>17.30 ± 0.13</td>
</tr>
<tr>
<td>3 - 7</td>
<td>23.20 ± 0.33*</td>
<td>23.00 ± 0.12*</td>
<td>22.22 ± 0.21</td>
<td>21.51 ± 0.23</td>
</tr>
<tr>
<td>3 - 8</td>
<td>19.07 ± 0.18*</td>
<td>19.04 ± 0.19*</td>
<td>18.40 ± 0.21*</td>
<td>17.72 ± 0.12</td>
</tr>
<tr>
<td>3 - 9</td>
<td>10.04 ± 0.15*</td>
<td>10.37 ± 0.23</td>
<td>10.71 ± 0.15</td>
<td>10.33 ± 0.14</td>
</tr>
<tr>
<td>Gonial angle (degrees)</td>
<td>83.21 ± 1.11*</td>
<td>87.62 ± 0.23</td>
<td>90.00 ± 1.04</td>
<td>86.60 ± 0.65</td>
</tr>
<tr>
<td>Net area (mm²)</td>
<td>82.58 ± 0.74</td>
<td>86.58 ± 1.02</td>
<td>82.56 ± 0.23</td>
<td>82.01 ± 0.18</td>
</tr>
</tbody>
</table>

*Difference statistically significant compared with group D.
#Difference statistically significant compared with group C.

TABLE 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Group A</th>
<th>Group B</th>
<th>Group C</th>
<th>Group D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angulation (degrees)</td>
<td>125.65 ± 1.40**</td>
<td>121.69 ± 1.61**</td>
<td>131.00 ± 0.54</td>
<td>131.50 ± 0.83</td>
</tr>
<tr>
<td>Anterior length (mm)</td>
<td>10.78 ± 0.30**</td>
<td>10.53 ± 0.61**</td>
<td>8.96 ± 0.14</td>
<td>8.90 ± 0.26</td>
</tr>
<tr>
<td>Posterior length (mm)</td>
<td>15.86 ± 0.22</td>
<td>15.25 ± 0.39</td>
<td>16.16 ± 0.16*</td>
<td>14.86 ± 0.32</td>
</tr>
<tr>
<td>Socket area (mm²)</td>
<td>34.69 ± 0.45*</td>
<td>33.93 ± 0.63*</td>
<td>36.72 ± 0.68*</td>
<td>30.80 ± 0.97</td>
</tr>
<tr>
<td>Anterior vertical location (mm):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 - 2'</td>
<td>1.79 ± 0.06*</td>
<td>1.75 ± 0.09*</td>
<td>1.38 ± 0.06</td>
<td>1.63 ± 0.05</td>
</tr>
<tr>
<td>10 - 10'</td>
<td>1.02 ± 0.07*</td>
<td>1.18 ± 0.09</td>
<td>1.39 ± 0.07</td>
<td>1.20 ± 0.04</td>
</tr>
<tr>
<td>Posterior vertical location (mm):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 - 12'</td>
<td>4.59 ± 0.46*</td>
<td>5.39 ± 0.23</td>
<td>5.06 ± 0.48</td>
<td>6.26 ± 0.29</td>
</tr>
<tr>
<td>12 - 12'</td>
<td>9.41 ± 0.16</td>
<td>9.57 ± 0.24*</td>
<td>9.44 ± 0.21</td>
<td>8.43 ± 0.37</td>
</tr>
<tr>
<td>Posterior horizontal location (mm):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 - 12</td>
<td>8.32 ± 0.63</td>
<td>8.96 ± 0.19</td>
<td>7.60 ± 0.23</td>
<td>7.60 ± 0.12</td>
</tr>
</tbody>
</table>

*Difference statistically significant compared with group D.
#Difference statistically significant compared with group C.

(group C) or when the latter was preceded by application of orthodontic forces (groups A and B). Horizontally, a number of changes were noted: Prolonged force application (group B) caused a significant decrease in anterior length, as compared with both control groups (C and D). Comparison of the values of the posterior length of the orthodontic groups (A and B) with control group C showed an increase in two of the measurements (3-5 and 3-6) in group B. Except for distance 3-9, all measurements of the posterior length in the orthodontic groups (A and B) were significantly increased, compared with control group D.

The experimental conditions caused fluctuations in the gonial angle, the only significant difference being found between groups A and B. The net mandibular area did not show significant changes in any of the study groups.

Socket (Table 2 and Fig. 1b).—Three months after cessation of orthodontic force application, the socket angulation in groups A and B was significantly more acute, compared with groups C and D. Although the prolonged loading (group B) produced a more severe “bending” of the socket than was observed after the more limited period of force application (group A), this difference between the groups was not statistically significant.

The anterior socket length in groups A and B increased to a similar degree, the attained values differing significantly from those in groups C and D. The posterior length in group C increased significantly, compared with group D, while in groups A and B, the increase in this parameter was not significant, compared with both control groups (C and D).

The socket area in groups A, B, and C increased significantly, compared with group D.

Vertically, the socket location changed into a more inferior position anteriorly and more superior posteriorly in both groups A and B, compared with the controls. In the anterior region, this transition was expressed by significant differences between the loaded (A and B) and the hypofunctional group (C). In the posterior region, the relocation was indicated by significant differences between the loaded groups and control group D.

Discussion.

Application of orthodontic forces to the mandibular incisor had a long-lasting influence on the morphology and location of the incisal socket, as well as on mandibular growth. The results obtained in groups A and B express the combined effect of mechanical loading followed by the virtual elimination of
functional occlusal forces. The experimental design of the study facilitated differentiation between the consequences of mechanical loading per se and its interference with adjustment of the incisal-mandibular complex to accelerated eruption.

The orthodontic loads affected primarily socket morphology, alveolar bone, and mandibular growth (Fig. 3). The loads significantly altered the angulation and anterior length of the socket, as inferred from the lack of change in these parameters under hypofunction only (group C). One may speculate that the more acute socket angulation three months after cessation of force (groups A and B) was due to the impact of the loads, which either induced deformation of the unmineralized progenitor compartment (Michaeli et al., 1985) or initiated a differential rate of development of the tooth-forming elements (Berkovitz, 1971), or both.

The increased anterior socket length in the two orthodontically treated groups was surprising, in view of the reported loss of alveolar bone in similar investigations (Michaeli et al., 1985) and the reduction in anterior mandibular length found in the current study. However, a possible posterior relocation of the most inferior point on the socket (Fig. 1b, point 13) as a result of orthodontic loading may explain the elongation of the anterior socket segment. It is also conceivable that the relocation is related to the changed socket angulation.

In some instances, the mechanical forces exerted a modifying effect upon the socket’s adaptability to functional demands. Thus, for example, hypofunction alone caused the socket area to increase significantly, compared with the intact control, a phenomenon that is explained by concomitant increases in tooth size and in the enamel-related periodontal ligament in hypofunctional incisors (Steigman et al., 1989). However, application of the loads reduced the adaptability to functional demands, as evidenced by the restrained increase in socket area in the orthodontically treated groups.

In the alveolar bone, under normal function, the width of the lingual plate exceeded that of the labial plate (group D, ratio 1.40:1.00), probably to meet the demands of load distribution during grinding activities. With prolonged elimination of the latter factor, both aspects of the alveolar bone achieved similar thicknesses (group C, ratio 1.04:1.00). This centering of the socket in the anterior region, which expresses functional adaptability to disuse, was not observed following mechanical loading. In these instances, the excessive thickness of the lingual bone, created in accordance with the direction in which orthodontic forces had been applied, persisted despite the three months of post-loading hypofunction.

The mandibular height, as measured in the present study, remained unaffected by both functional changes and mechanical loading. The decrease in anterior mandibular length after four weeks of spring application might be explained by the combination of alveolar bone loss and the pronounced change in socket angulation. A possible role in the decrease may have been played by a slight anterior tipping of the first molar due to spring activation. In the posterior region, the mandible responded to removal of occlusal contact by increased condylar growth and periosteal bone apposition at the lower border of the angular process, while mechanical loading (under similar conditions) caused an overall enlargement of the posterior part of the mandible.

The increments in the posterior mandibular part may be interpreted as an orthopedic effect of intra-orbital orthodontic forces, which act via bone trajectories. Such possibility was suggested by other investigators in experimental and clinical situations (Cleall, 1974; Baumrind et al., 1983). Admittedly, the loads utilized in the current study exceeded (by about 20%) the optimal orthodontic force for rats, which was established at 16 g (Steigman and Michaeli, 1981); still, an orthopedic effect of orthodontic spring activation would be difficult to negate.

A comparison between the two- and four-week-loaded groups failed to show statistically significant differences in any of the parameters measured. However, the greater “bending” of the socket, the more pronounced shortening of the alveolar bone (mandibular anterior length), and the larger increment in condylar growth (value 3-5) in group B vs. group A suggest a possible influence of load duration. Since in the present study the difference in loading time between the two groups was only two weeks, it may be of interest to broaden the scope and investigate the temporal effect of force application.

It should be remembered that the present results were recorded three months after loading of the incisors had ceased. In this interval, the animals of groups A, B, and C were kept under identical experimental conditions. It would therefore be reasonable to expect that in this intervening time period the processes of dental and periodontal tissue renewal and of bone growth would have compensated for the effects of tooth loading. However, the fact that, in the animals in which the teeth were subjected to force application, the values of the examined parameters failed to return to control level points to the long-lasting effects of mechanical loading. A study of much longer duration, now in progress in our laboratory, will, it is hoped, elucidate the degree of permanence of these changes.

The sequela of the mechanical forces applied in the present investigation closely resemble the conditions actually existing under excessive occlusal forces, or hyperfunction (Brin et al., 1989), implying that both types of stress trigger a biological process that finds its expression in changes in tooth socket and in mandibular growth.

REFERENCES


